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ABSTRACT

Harvesting operations of forests on the Cape Breton Highlands have resulted in young successional stands that provide optimum habitat for the snowshow hare (Lepus americanus Erx.). Extensive girdling of balsam fir (Abies balsamea (L.) Mill) boles in dense mid-to-late regeneration stands has occurred. Volume loss from mortality was not as high in an open stand as in a dense stand. Small diameter trees were girdled more frequently, but, the largest volume loss from decreased increment occurred in trees of greater than 3.0 cm diameter at breast height. In a dense stand of 32 120 stems/ha, about 5397 stems/ha (7.23 m^3/ha) may be lost in 10 years from mortality caused by the hares. Stem analysis of 15 trees showed an annual loss in volume increment of 1.29 m^3/ha due to girdling. In a stand as dense as the one studied, this loss would be beneficial by uniformly reducing stand density.

RESUME

Les opérations d'exploitation forestière sur les hauteurs du Cap-Breton ont eu pour résultat de produire de jeune peuplements de régénération qui constituent un habitat optimum pour le lièvre d'Amérique (Lepus americanus Erx.). On a relevé une annélation considérable des fûts de sapin baumier (Abies balsamea (L). Mill.) dans les peuplements denses dont la régénération sont au stade intermédiaire a avancé. La perte en volume dûe à la mortalité n'était pas aussi élevée dans un peuplement ouvert que dans un peuplement dense. Les arbres de petit diamètre se trouvaient annélés plus fréquemment, mais ceux dont le diamètre à hauteur de poitrine était superieur à 3 cm accusaient la plus forte perte en volume par perte de croissance. Dans un peuplement dense de 32 120 tiges/ha, il peut y avoir une perte d'environ 5397 tiges/ha (7.23 m^3/ha) en 10 ans par suite de la mortalité imputable aux lièvres. L'analyse des tiges de 15 arbres a fait ressortir une perte annuelle d'accroissement en volume de 1.29 m^3/ha causée par l'annélation des tiges. Dans un peuplement aussi dense que celui étudié, une telle perte serait bénéfique en ce qu'elle réduirait la densité du peuplement de manière uniforme.

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INTRODUCTION

Forests on the Cape Breton Highlands have been extensively harvested over the past 20 years, resulting in large areas being converted to early successional stages. Parker (1980) found that these mid-to-late regeneration stands of mixed conifer-deciduous forests provide optimum conditions for high populations of the snowshoe hare (Lepus americanus Erx.).

High hare populations in stands of advanced, naturally regenerating balsam fir (Abies balsamea (L.) Mill) are evidenced by exposed wood on the boles of fir trees, as hares peel and eat the bark, a common food source in winter. Many trees may die as a result. Because of the high density of trees in these fir stands, thinning is inevitable, whether by natural suppression, man, or hares. While results of the conventional types of thinning may be predicted, little is known of the effect of thinning by snowshoe hares.

The objectives of this study were to examine the spatial distribution and frequency of hare girdling and their effects on the development of two 25-year-old balsam fir stands with widely different densities. The specific questions addressed were: (1) Is girdling more pronounced in a dense stand than in an open stand? (2) Is the intensity of girdling associated with tree diameter at breast height (dbh)? (3) Does intensive girdling reduce volume increment? (4) Is stand development altered by girdling?

METHODS

The Study Area

The two balsam fir stands are located on the Cape Breton Highlands, Nova Scotia, within 200 m of each other on similar forest sites (Fig. 1). The stands consist of mainly pure balsam fir with a few scattered white spruce (Picea glauca (Moench) Voss), white birch (Betula papyrifera Marsh.), yellow birch (Betula alleghaniensis Britton) and sugar maple (Acer saccharum Marsh). The ground vegetation consists of a mixture of mosses, herbs, and shrubs and is described in more detail elsewhere (Piene In prep.). The soil is a ferro-humic podzol with a marked leached layer (Ae horizon). The B-horizon is from 15 to 35 cm thick.

Data Collection and Analysis

Data were collected at the end of September, 1979 from one plot (15.8 by 15.8 m) located in each of the two forest stands. These plots had been established in 1976 to study growth responses to spacing (Piene In prep.). One stand, termed the "dense stand", had 32 120 stems/ha (a between-tree spacing of 0.31 m) while the other, the "open" stand, had 6962 stems/ha (a between-tree spacing of 1.43 m) (Table 1). The two plots were sampled systematically by choosing four transects 15.8 m long and 1 m wide. The two middle lines were separated by 5 m, the others by intervals of 3 m. This corresponded to a 25% sampling intensity which was judged sufficient from analysis of preliminary data (August, 1979) from the same plot.

On each transect, dbh, percent circumference girdled (measured at the point of maximum width of girdle), crown ratio (percent of the length of stem with living branches), and crown class were measured for each living tree. Percent circumference girdled was used to quantify intensity of girdling. Crown ratio and crown class indicated the present vigour and health of the tree. Dispersion of trees within each transect was mapped and if a tree was dead, the cause of death (girdling or suppression) was noted. Diameter at breast height and height of 40 trees

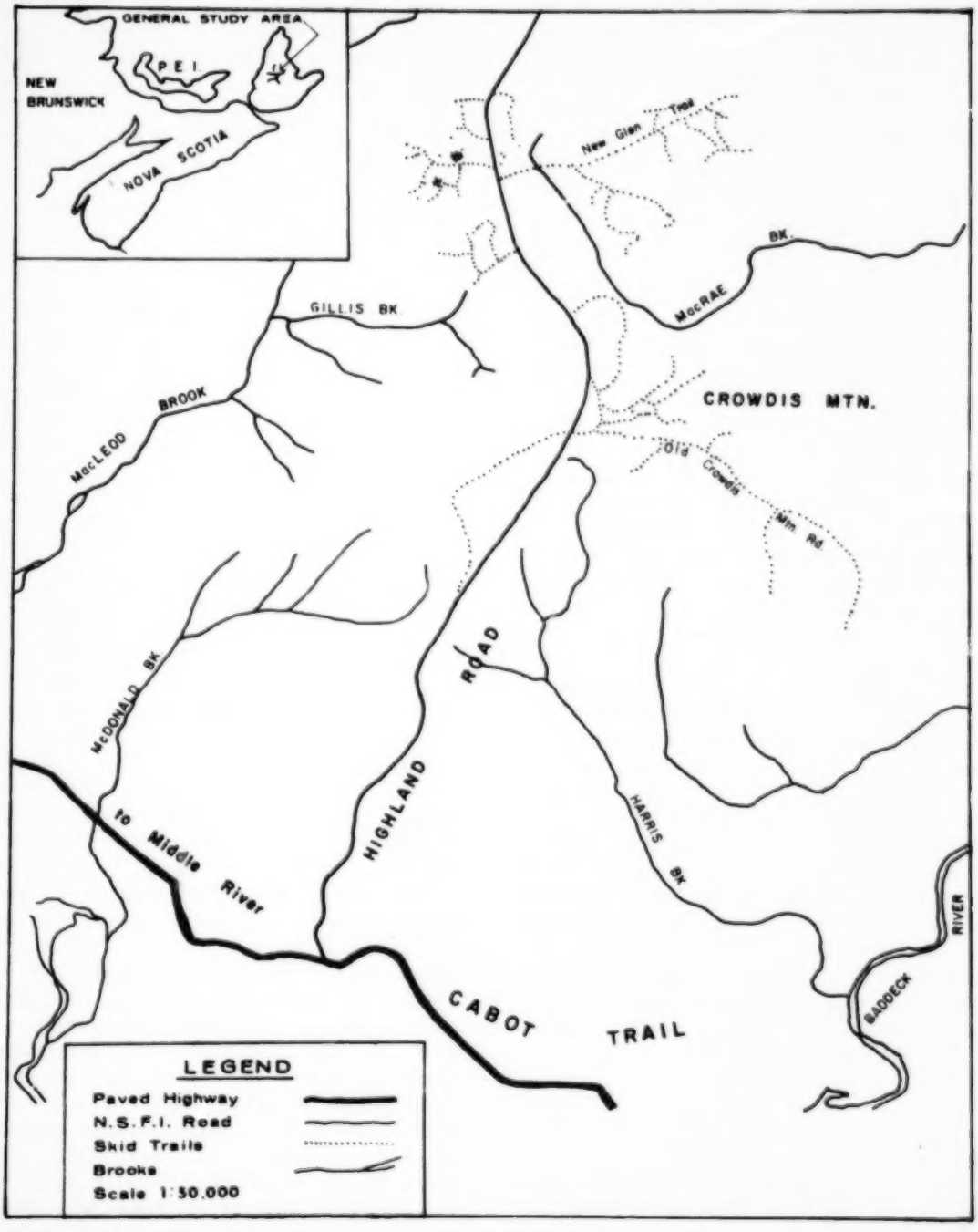

Fig. 1. Location of the two balsam fir stands on the Cape Breton Highlands.

Table 1. Stand description of the two sampled plots, Crowdis Mountain, area, Cape Breton Highlands

Plot	No. trees sampled[1]	Mean dbh (cm)	Mean height (m)	Stem/ha	Mean between-tree spacing (m)	m^3/ha
Dense	203	3.4	2.85	32 120	0.31	93.6
Open	44	8.1	6.40	6 962	1.43	201.1

[1] Corresponds to 25% sample of trees on plot.

were measured within each plot to construct a height-diameter curve in order to estimate stand volume.

Bartlett's test (Zar 1974), G-test (Sokal and Rohlf 1969), one-sample runs test for randomness (Daniel 1978 pp.53-58), Mann-Whitney test (Daniel 1978), and linear regression were used in data analysis.

Based on observations in the field, the critical level of girdling which will cause mortality within 10 years has been conservatively estimated to be 75% of the stem circumference. This level was used to estimate loss of volume in stands due to mortality of trees severely girdled by hares.

Stem Analysis

Fifteen trees from the dense stand were selected for stem analysis to determine the effect of girdling on volume increment. (Because of minimal girdling in the open stand, no trees were collected for stem analysis from that area.) These trees were removed from locations adjacent to the sample plot. Three trees with over half of their circumference girdled and two control trees that had not been girdled were chosen from three dbh classes, 0-1.9, 2.0-3.9, and 4.0-5.9 cm. Discs were collected from every second internode down each tree and ring widths were measured to the nearest 0.01 mm with a Holman auto-micrometer along the average radius of each disc. Measurements for each tree and distances between sequential sections taken from each tree were recorded on cassette tape and transferred to a computer. Annual volume increment and total tree volume were then calculated by adding the volumes of each section.

RESULTS

Open Plot

Statistical analyses of the distribution of girdled trees within dbh classes were not performed for the open plot as only 7 of the 144 trees sampled were girdled, none of these having bark removed from more than 75% of the stem circumference. (Fig. 2). Girdling occurred in the small dbh classes only. Since no tree had 75% or more of its bark circumference removed, it is predicted that girdling will cause no mortality within this open plot. However, over the next few years decreased annual growth of the girdled trees will probably result in a slightly lower total stand volume. Growth measurements were not taken in this stand as the frequency of heavily girdled trees was insufficient.

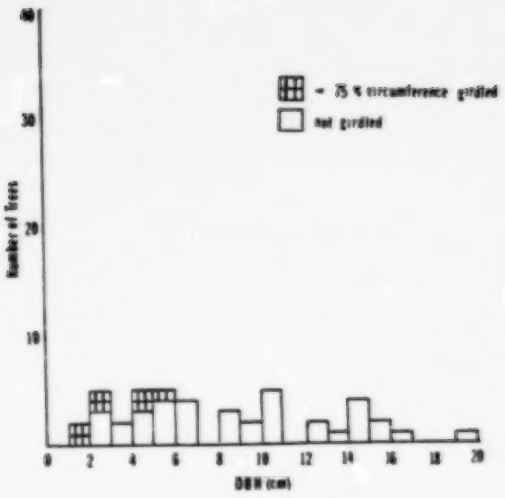

Fig. 2. Distribution of girdled and non-girdled balsam fir trees (n=144) in the open plot, Crowdis Mountain area, Cape Breton Highlands.

Dense Plot

Of 203 trees measured in the dense plot, 120 (59%) were girdled, 34 (17%) with more than 75% of their bark circumference removed (Fig. 3). The number of trees girdled within each dbh class was different from that expected, based on the distribution of diameters in the plot (G-test, $P<0.01$). As in the open plot, small diameter trees were selected by the hares (Fig. 3). Similarly, the number of trees in each dbh class with more than 75% of their bark circumference girdled was different (G test, $P<0.05$) than the number expected. Using the assumption that trees with more than 75% of their bark circumference girdled will die within 10 years, the density of this plot will decrease by about 5397 stems/ha (17%) or 7.23 m^3/ha (11% of total stand volume). On an annual basis, this is a decrease of 1.1% as a result of snowshoe hare girdling. This is double the average annual mortality from porcupine (Erethizon dorsatum L.) feeding on a predominantly black spruce (Picea mariana) (Mill.) B.S.P. stand in Sunbury County, New Brunswick (Reeks 1942).

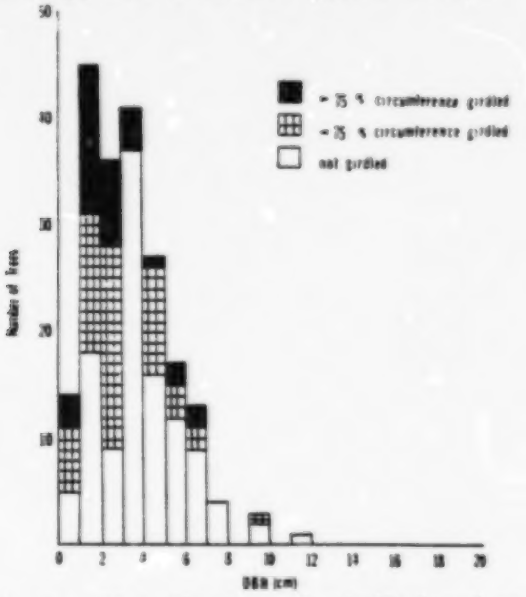

Fig. 3. Distribution of girdled and non-girdled balsam fir trees (n=203) in the dense plot, Crowdis Mountain area, Cape Breton Highlands.

After determining that small trees were browsed more frequently than large trees, a regression analysis was performed to determine whether the intensity of girdling was higher in the smaller diameter classes. Percent bark circumference girdled showed homogeneity of variance among dbh classes (Bartlett's test; $P<0.05$) and was used as an indicator of girdling intensity in the regression. Coefficients of determination (r^2) indicated no linear association (Table 2) between dbh and percent circumference girdled. However, in general, a smaller diameter tree exhibited a higher percentage of its diameter girdled.

The spatial distribution of trees with more than 75% bark circumference girdled was analyzed to compare their dispersion with that of a uniform thinning executed by man. Three of the four transects exhibited essentially uniform spacing of the culled trees (one-sample runs test for randomness, P 0.05).

Table 2. Regression between arcsine transformed percent circumferences of balsam fir trees girdled by snowshoe hare and diameter at breast height, in the dense plot, Crowdis Mountain area, Cape Breton Highlands

Transect	Intercept (transformed % girdled)	Slope	r^2
1	48.92	-6.8211	0.169
2	50.80	-5.8787	0.146
3	41.73	-6.0132	0.175
4	42.69	-4.3151	0.063
Total	45.83	-5.5530	0.128

Tree Growth Analysis

The time that girdling occurred was determined from cross-sections of girdled portions of the stems used in stem analysis. The most of the girdling occurred in 1977. This agrees with Parker (1980) who estimated that the peak population of hares occurred in 1977, reaching 10 hares/ha in late regeneration stands on the Cape Breton Highlands. Older girdles, that occurred 3 and 4 years previously (1975 and 1976), also were present but mainly on the large trees (Table 3).

To estimate the growth after girdling (1978 and 1979) total volume growth curves were drawn for each tree from analysis of their actual annual growth. A predicted growth curve for the years following was produced by fitting a line through the volume seven years prior to girdling (usually 1970 to 1977) and extending this line to years 1978 and 1979. This was done for both girdled and control trees. All growth curves for both girdled and control trees

Table 3. Description of balsam fir used in stem analysis and the girdling damage caused by snowshoe hare in the dense plot, Crowdis Mountain area, Cape Breton Highlands

Tree No.	Dbh	Ht (m)	Surface area girdled (cm^2)				Circumference girdled (%)
			1975	1976	1977	Total	
*101	1.3	1.61	0	0	0	0	0
*102	1.6	1.83	0	0	0	0	0
121	1.2	1.83	0	0	69.3	69.3	65
122	1.3	1.47	0	0	33.7	33.7	55
123	1.8	2.08	10.6	0	63.7	74.3	75
*201	2.2	1.52	0	0	0	0	0
*202	3.9	3.26	0	0	0	0	0
221	3.8	3.85	94.1	0	200.6	294.7	57
222	3.0	2.46	0	39.9	217.6	257.4	75
223	2.7	2.10	1.5	0	147.7	149.2	65
*301	4.8	4.16	0	0	0	0	0
*302	4.8	3.59	0	0	0	0	0
321	4.4	3.61	209.8	0	47.9	257.7	66
322	5.4	4.49	0	242.0	128.1	370.1	67
323	5.6	3.78	0	0	1431.0	1431.0	100

* Control

showed a strong linear relationship as the coefficients of determination (r^2) ranged from 0.992 to 0.998. Differences between actual volume and predicted volume represent volume loss (if negative) or volume gain (if positive). These differences were calculated for each tree during the years 1978 and 1979 (Table 4).

Overall, girdled trees showed a significantly higher volume loss than control trees (Mann Whitney test, $P<0.05$). Each diameter class was then tested separately and both larger dbh classes (2.0-3.9 cm and 4.0-5.9 cm) again showed a significantly higher volume loss in girdled trees. The 0-1.9-cm dbh class however, showed no significant difference.

By subtracting the average volume growth per tree of the girdled trees from that of the control trees, the amount of wood lost because of hare damage could be calculated. Since 1977, a total of 216 and 850 cm^3/tree of wood volume was lost in dbh classes 2.0-3.9 and 4.0-5.9, respectively, as a result of hare girdling. This amounts to 2.59 m^3/ha total volume lost in 2 years from trees being girdled more than 50% by snowshoe hares. This is equivalent to an average annual loss of 1.4% of the total stand volume.

Table 4. Difference between actual volume and predicted volume for girdled and control trees, 1978 and 1979, in the dense plot, Crowdis Mountain area, Cape Breton Highlands

Dbh Class (cm)	Difference between actual and predicted volume (cm^3)*					
	Control			Girdled		
	Tree No.	1978	1979	Tree No.	1978	1979
0.0-1.9	101	- 35.7**	- 42.6	121	-111.3	-158.9
	102	-149.2	-246.6	122	-108.3	-160.6
				123	- 81.0	-123.7
Average		- 92.5	-144.6		-100.2	-147.7
2.0-3.9	201	- 9.6	+ 53.4	221	-297.8	-566.3
	202	-124.7	-226.0	222	- 68.7	-228.5
				223	-101.5	-111.3
Average		- 67.2	- 86.3		-156.0	-302.0
4.0-5.9	301	- 18.8	+163.0	321	-368.8	-615.6
	302	-156.8	- 62.7	322	-368.6	-642.2
				323	-454.8	-1,143.2
Average		- 87.8	+ 50.2		-397.4	-800.3

* Estimated by fitting a line to total tree volumes from 1970 to 1977 and extending this line to years 1978 and 1979.

** Negative sign denotes loss of volume from predicted value.

DISCUSSION

Girdling is often used to kill undesirable, over-topping trees and to release growth in young stands (Smith 1962). Severing or peeling of the bark and cambium arrests the production of new inner xylem and outer phloem conductive tissues. Water and carbohydrates, essential to the tree's existence, can no longer be translocated (Westveld 1942; Smith 1962). Even so, the tree may live several years, as roots function until the stored carbohydrates are exhausted.

Of several common methods of manual girdling, namely notching, peeling, and hacking (Westveld 1942), hare browsing best simulates peeling, in which only the phloem and cambium are removed. The uninjured xylem continues to transmit water from the base to the top of the stem. However, parasites often attack the damaged tree causing the xylem to lose its power of conduction, eventually killing the tree. Basal scars afford entry to wood rotting fungi, so that trees may become worthless culls if not killed (Cook and Hamilton 1957). This type of injury directly affects the butt log which is the most valuable portion of the tree (Cook and Hamilton 1957).

In the same stands as those under study, Stereum sanguinolentum and Amylostereum chailletii were found in association with extensive trunk rot in hare damaged trees. The open wounds apparently provided entry points for S. sanguinolentum (Wall, Pers. comm., 1980)[1]. There was no decay in comparable uninjured trees.

Reduction in stand volume and number of stems per hectare is much greater in the dense stand than in the more open one. Within 10 years, it is projected that 11% (1.1% annually) of the total volume in the dense stand will be lost as a result of hare-caused mortality. This is in addition to the annual volume loss of 1.4% of the total stand estimated from stem analysis.

Mortality due to girdling was not predicted for the open stand since no tree had more than 75% of its bark circumference girdled. This seems reasonable, as snowshoe hares on the Cape Breton Highlands prefer dense stands with a crown closure of 70-80% and a mean tree height of 2-3 m (Parker 1980) such as the dense stand studied.

Smaller diameter trees are associated with a higher intensity of girdling. Not only were more trees girdled in the smaller diameter classes, but also a larger percent of their bark circumference was removed.

Stand volume increment was reduced by snowshow hare girdling. Although the highest percent of bark circumference girdled usually occurred on smaller trees, the reduction in absolute terms in volume increment, solely from girdling, was not as great on small trees as on large trees. This is because smaller trees were already exhibiting low increment as a result of heavy competition and suppression.

The most significant loss of volume in the stand from girdling occurs in the larger diameter trees (>3.0 cm). These well-established, intermediate to dominant trees are ordinarily growing well and show excellent chances of survival. Girdling causes a rapid decline in growth and lessens their probability of survival. Volume loss from girdling of 1.29 m^3/ha per year is substantial and, assuming that these extensively girdled trees do not heal, this loss will accumulate in future years. In the dense stand studied, the estimated loss of volume within 10 years from mortality is 7.23 m^3/ha or 5397 stems/ha. This increases the average growing space for each tree from 0.3 m to 0.4 m. Despite the immediate volume loss

[1] R.E. Wall, Research Scientist, Maritimes Forest Research Centre, Fredericton, N.B.

incurred, it is likely that the uniformly distributed hare-caused mortality will ultimately be beneficial to stand growth, because the original density was unreasonably high for maximum merchantable volume increment.

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